

This invention relates to a spectrometer module, a monitor module, a monitoring unit and a monitoring system for use in monitoring an optical network.

Background art

One field of technology is fibre optical communication systems, that are used for transferring large amount of information over large distances. Such system comprise a plurality of different network elements, being interconnected to form a communication network. However, as these networks are becoming larger and larger, and including more and more sophisticated network components, the risk for network faults is increasing rapidly. Consequently, there is a need for surveillance systems, keeping track of the optical signals being transmitted in the network, and reporting when an error has occurred.

Furthermore, the communication speed in the optical networks, such as WDM networks are constantly increasing, resulting in the need of less capacity demanding communication protocols. Thereby, existing protocols such as SDH/SONET, having built-in monitoring functions need to be replaced or at least supplemented. This has lead to the development of systems monitoring data in the optical domain.

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which is based on a sub-carrier modulation of the signal, is complex and expensive.

Summary of the invention

5 Consequently, an object of this invention is to achieve a spectrometer module, a monitor module, a monitoring unit and a monitoring system for use in monitoring an optical network, overcoming the above-mentioned drawbacks with the prior art.

10 A further object is to achieve a way of measuring properties of an optical signal, such as power, state of polarisation and degree of polarisation versus wavelength in an efficient way.

 Yet a further object is to achieve a spectrometry
15 device, overcoming the drawbacks with the prior art.

 Further objects of this invention are evident from the following description of the invention.

 The above and other objects are wholly or partly achieved by a spectrometer module comprising:

20 -an input, for receiving an incoming optical signal,
 -a variable differential group delay (DGD) element, for applying a variable birefringence retardation to said incoming optical signal,
 -a detector unit for detecting the power of a defined
25 state of polarisation of a signal exiting said variable DGD element.

 By using a variable DGD element in a spectrometer module, it is possible to perform measurements on an incoming optical light signal, for detecting parameters
30 such as polarization state and degree of polarisation as a function of the wavelength of the incoming signal.

 In accordance with a first embodiment of the invention, said variable DGD element is implemented spatially. Preferably, said variable DGD element comprises a plural-
35 ity of laterally spaced sub-elements having different optical lengths, whereby different parts of the incoming optical signal is arranged to be transmitted through dif-

5 Thereby, the DGD element is optimally used. Moreover, said variable DGD element suitably comprises a plane incidence surface, being essentially orthogonal to the optical signal path, and a stepped exit surface.

20 According to a second embodiment of the invention,
said variable DGD element is implemented temporally, by
use of an electrical control signal that changes the DGD
with time. Preferably, said variable DGD element is com-
25 prised by a birefringent system, being essentially sand-
wiched between a first and a second reflective element,
whereby said incoming optical signal is arranged to be
reflected between said reflective elements one or more
times before outputted from said birefringent system.
Suitably, said first and second reflective elements are
30 constituted by a first and second mirror element, respec-
tively. Alternatively, said first and second reflective
elements are constituted by a first and a second retrore-
flector, respectively. By using the above reflections
systems, the same birefringent element may be utilized
35 many times.

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pharmaceutical industry, or in any other field in which spectrometry is applied.

Further, the above and other objects are wholly or partly achieved by a monitor module for measuring properties such as power, state of polarisation and degree of polarisation of an incoming optical signal as a function of wavelength, said monitor module comprising:

- a polarisation control module being connected with a control unit,
- a spectrometer module, being connected with said control unit, and
- a polariser being placed between said polarisation control module and spectrometer module.

Preferably, said spectrometer module is as described above. Such a monitor module may for example be used for monitoring the above parameters in an optical network, such as an WDM network. Suitably, said polarisation control module comprises:

- a first birefringent element,
 - a second birefringent element,
- each of said birefringent elements being connected with a power source for individual control of the birefringence of said first and second birefringent element, respectively. According with an embodiment, the birefringent eigenaxes of said second birefringent element is rotated by 45 degrees in relation to the birefringent eigenaxes of said first birefringent element. Alternatively, the birefringent eigenaxes of said first and second birefringent elements are coinciding, and a quarter wave element, being rotated by 45 degrees in relation to the birefringent eigenaxes of said birefringent elements, is arranged between said first and second birefringent elements.

The above and other objects are also wholly or partly achieved by a unit for monitoring an optical signal, being transmitted in an optical network, said unit comprising:

- a coupler, being arranged to be inserted along a optical

transmission path of said optical network, said coupler having a main in- and output, respectively, for receiving and transmitting said optical signal and at least one drop output, to which a portion of said optical signal is droppable, said drop output being connected with one of a spectrometer module as described above and a monitor module as described above. Such a monitoring unit may be installed in an optical network, in a position which is desired to monitor.

Finally, the above and other objects are also wholly or partly achieved by a monitoring system for an optical network, comprising a plurality of network elements, such as transmitters, receivers, transmission lines, amplifiers or the like, said monitoring system comprising:

- two or more monitoring stations, each of said monitoring stations being positioned between two network elements of said optical network and each of said stations comprising one of a spectrometer module as described above, a monitor module above and a monitoring unit as described above and
- a monitoring hub, being connected with each monitoring station, said hub being arranged to receive measured signal data from each of said monitoring stations, and said monitoring hub comprising a processing unit for processing said measured signal data.

Alternatively, the objects are wholly or partly achieved by a monitoring system for an optical network, comprising a plurality of network elements, such as transmitters, receivers, transmission lines, amplifiers or the like, said monitoring system comprising:

- two or more monitoring stations, each of said monitoring stations being positioned between two network elements of said optical network, each of said stations being arranged to measure power, state of polarisation and degree of polarisation of an optical signal entering said monitoring station via said network,
- a monitoring hub, being connected with each monitoring

station, said hub being arranged to receive measured signal data from each of said monitoring stations, and said monitoring hub comprising a processing unit for processing said measured signal data.

5 Thereby, the invention may be used for gaining information regarding the function of an entire network, for example enabling quick location of faults.

 The above monitoring system as well as the above monitoring module may be used for monitoring signal data
10 quality in a wavelength division multiplexed (WDM) fibre optical communication system. Further, the spectrometer module above may be used as a standalone spectrometer device, as stated above.

 Finally, the above objects are wholly or partly
15 achieved by a method of monitoring and measuring properties such as power, state of polarisation and degree of polarisation of an incoming optical signal as a function of wavelength, the method comprising the steps of:
 -inputting said incoming optical signal to a variable DGD
20 element,
 -applying a variable birefringence retardation to said incoming optical signal by letting it pass said variable DGD element, and
 -detecting the power of the signal exiting said variable
25 DGD element, having a determined state of polarisation.

 Preferably, said variable DGD element is comprised in a spectrometer module as described above. Moreover, the method suitably comprises the step of dropping said incoming optical signal from a wavelength division multi-
30 plexed (WDM) fibre optical communication system that is to be monitored.

Brief description of the drawings

 Currently preferred embodiments of the present inven-
35 tion will now be described in closer detail, with reference to the accompanying drawings.

Fig 1 is a schematic drawing of a first embodiment of the inventive spectrometer module.

Fig 2 is an alternative embodiment of the construction as shown in fig 1, being independent upon the polarisation of the incoming optical signal.

Fig 3 is a schematic drawing of a second embodiment of the inventive spectrometer module.

Fig 4 is yet another schematic drawing of a third embodiment of the inventive spectrometer module showing only a spectrometer section of said module.

Fig 5 is a schematic drawing of a fourth embodiment of the inventive spectrometer module showing only a spectrometer section of said module.

Fig 6 is a schematic drawing of a fifth embodiment of the inventive spectrometer module showing only a spectrometer section of said module.

Fig 7 is a schematic drawing of a monitor module, comprising a spectrometer module as shown in any one of the drawings 1-6.

Fig 8a and 8b is a schematic view showing two implementations of a polarisation control module, for use in a monitor module as shown in fig 7.

Fig 9 shows a monitoring unit for insertion in an optical communication system, said monitoring unit comprising a monitoring module as shown in fig 7.

Fig 10 is a schematic drawing of an optical communication network, in which a plurality of monitoring units as shown in fig 9 is used for monitoring optical signal transmission in said network.

Detailed description of preferred embodiments of the Invention

A schematic drawing of a spectrometer module in accordance with the invention is shown in fig 1. The spectrometer module comprises a variable DGD (differential group delay) element 11 and a detector unit 13. This embodiment also comprises a polarizer 12, being arranged

between said variable DGD element 11 and said detector unit 13 and being non-aligned with the birefringent axes of the DGD element.

An incoming light signal 14, having a determined, well-defined state of polarisation may be inputted to said variable DGD element 11, having birefringent eigenaxes. In the embodiment shown in fig 1, the variable DGD element is electrically variable, meaning that an electric field may be applied over said DGD element 11, in order to change the birefringence of said variable DGD element 11. For this purpose, the variable DGD element is arranged between a first and second electrode (not shown) being connected with an electronic control unit. However, it shall be mentioned that other ways of achieving a variable DGD are possible. For example, an acoustic-optical transducer (not shown) may be connected with said variable DGD element 11 in order to change the birefringence of the DGD element 11 by applying an acoustic or mechanical wave through the DGD element 11.

The incoming optical signal is arranged to have such a polarisation state that light is injected in both birefringence eigenaxes of said variable DGD element 11. Thereby, the optical signal will experience birefringence when propagating through said variable DGD element 11. Furthermore, the experienced birefringence may be varied by for example applying an electrical field over the variable DGD element 11.

After the variable DGD element, the optical signal is arranged to pass said polarizer 12, whereafter the power of said optical signal is detected by means of said detector unit 13.

Consequently, the power spectrum of the incoming optical signal 14 may be deduced by putting the variable DGD element in a plurality of birefringence states, by for example applying different electrical fields to the DGD element, and measuring the corresponding detector power level for each birefringence state. The purpose of

the spectrometer module is to extract the wavelength spectrum of the incoming optical signal 14, i.e. to obtain the power level at the various optical wavelengths. To do this a variable birefringence retardation is applied to the signal. The polarization state of a signal after passing such an element will vary periodically with the optical frequency, with a period given by $1/\text{DGD}$ where DGD is the differential group delay of the element. If the DGD in the birefringent element is electrically tunable, a tunable optical transfer function is achieved. After passing the polarizer, the wavelength components of the optical signal will attenuate differently, depending on what DGD has been applied. Consequently, the signal reaching the detector unit will be dependant upon the wavelength contents of the signal as well as upon the applied DGD. Thus, by measuring the detected power after a polarizer for many different values of the DGD, we will be able to compute the power spectrum of the signal. This is the physical background for the spectrometer module described in this document.

Furthermore, by outputting the power information from said detector unit 13 to an electronic processing unit 16, other parameters, such as power spectrum, state of polarisation and degree of polarisation of the incoming optical signal may be computed.

A second embodiment of the invention is shown in fig 3. In this case, an incoming, polarized, slightly diverging optical signal beam 114 is arranged to hit a birefringent element 111, which has continuously decreasing thickness (and thereby differential group delay) in one transverse direction (denoted x in the figure) related to the signal path. The polarization state after such a birefringent element 111 will continuously change spatially in the x-direction, with a rotation rate determined by the wavelength of the signal. Using a lens 112 this spatial polarization rotation will be transformed to a point in a Fourier (focal) plane 117 of the lens 112, where the

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- Arranging a lateral polarization controller in front of the DGD elements 211 so that the polarization state in to each sub-element can be controlled.

A fourth embodiment of a DGD element for use in a spectrometer module according to the invention is shown in fig 5. Here, a voltage controls the differential group delay of a birefringent element directly. An efficient way of doing this is to use a multipass structure, in which the light passes the same birefringent system several times. In the implementation shown in fig 5, an incoming optical light signal 314, having a well-defined state of polarization, is arranged to bounce back and forth between a first and a second mirror 312, 313 with a slightly tilted beam propagation direction, so that the beam 314 hits a birefringent system 311, being arranged between said mirrors 312,313, several times. The birefringent system 311 may contain an arbitrary set of birefringent and electrically controlled elements in any orientations, but it must contain a minimum of two birefringent elements of which at least one should have a differential group delay. Additionally, one birefringent element is electrically controlled by means of an electrical control unit. By electrically altering the birefringence of this electrically controlled element, the net birefringence of the multipass structure as a whole will be altered, and thereby an electrically controllable DGD element has been realized. The maximum amount of DGD that can be achieved in this manner will be the equal to the DGD of the birefringent system 311 times the number of passes through this system 311. This kind of multipass structure may replace the DGD element 11 in a structure as shown in fig 1.

A fifth embodiment of a DGD element for use in a spectrometer module according to the invention is shown in fig 6. This embodiment shows an implementation of a multi-pass structure, using retroreflectors. It is functionally similar with the embodiment shown in fig 5. In

30 An alternative embodiment of the invention, of which an example is depicted in fig 2, will hereinafter be described. Here, a spectrometer module as shown in fig 1, is used to generate a spectrometer device, for use as a standalone system for spectrometry. For such an application it is vital, that the device is independent of the polarization of the incoming light. This may be achieved by using a polarization diversity scheme as shown in Fig-

30 A spectrometer module 1 as described above with reference to fig 1, 3, 4, 5 or 6 may be comprised in a monitor module 2, as shown in fig 7. The purpose of the monitor module 2 is to provide a system that is able to measure power, state of polarization and degree of polarization of an incoming optical signal 4 as a function of wavelength, and in a preferred embodiment the general layout of a monitor module is shown in figure 7. The sys-

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alternative operation scheme drives the polarization control module 5 and the spectrometer module 1 at different frequencies, and spectral analysis of the electrical signal from the detector can then be used to extract the desired optical signal properties.

Two embodiments of the polarization control module 5, as described above, will hereinafter be described, with reference to fig 8a and fig 8b. The incoming light 4 hits a first and a second electrically controlled polarization waveplate 5a, 5b in sequence, said waveplates 5a, 5b being connected with said electronic polarization control unit 7. The waveplates 5a, 5b can be either oriented so that their birefringence axis does not line up, as shown in figure 8a, or have aligned birefringence axis but with a quarter-wave retarder 5c being arranged between said waveplate 5a, 5b with dealigned axes as shown in figure 5b. Examples of physical implementation of the waveplates 5a, 5b can be electro-optic crystals (in integrated, bulk optics, or liquid crystal fashion), electromechanical fiber squeezers, electromagnetically controlled Faraday rotators, or other schemes as described e.g. in the paper "Polarization-State Control Schemes for Homodyne and Heterodyne Optical Fiber Communications" by T. Okoshi, IEEE J. of Lightwave Technology, pp. 1232-1237, vol. LT-3, 1985, which is hereby incorporated herein by reference. The waveplates 5a, 5b change the polarization state of the signal 4 in a controlled manner, and measurement of the power level after a polarizer will enable the state of polarization to be determined. The function of the polarization control section 5 as shown in fig 8a will hereinafter be described. The optical signal 4 to be detected falls into a birefringent waveplate 5a, changing the exit polarization state of the signal 4 as a function of an applied voltage V_1 . The birefringent axes of the waveplates, representing states of polarization that may pass the waveplate unaltered, are shown with arrows in fig 8a-b. Consequently the birefringent axes of the first

and second waveplates 5a, 5b are arranged with an angle of 45 degrees in relation to each other, so that light entering the first waveplate 5a along its birefringent axes may be controlled by the second waveplate 5b, having
5 an variable applied voltage V2. In fig 8b, said quarter wave plate 5c is arranged to provide the same effect, although the axes of the waveplates coincide. It shall be noted that the above described polarization control module may be used with any spectrometer module, not only
10 the ones being described above.

A monitor module 2 as described above, and as shown in fig 7, may be incorporated in a monitoring unit 20. The monitoring unit 20, as shown in fig 9 is intended to be used in an optical communication network, as will be
15 described below. The monitoring unit 20 comprises an optical four-way directional coupler 21 that is connectable with a first and a second transmission line 22, 23 for an optical signal S. By means of said directional coupler 21, a small portion, generally about 1%, may be dropped
20 from the transmission line to a monitor module 2, being connected with one port of said directional coupler 21. This small portion constitutes the incoming light signal 4, falling into the monitor module 2, as described above. Further, an additional small portion of reflected light
25 from the transmission line 22,23 may be detected as well, by positioning a detector 24 in a backward port of the coupler 21, as shown in fig 9. Alternatively, for use with a bi-directional transmission line 22,23, transmitting light in both directions, a further monitor module
30 may be positioned in said backward port, instead of said detector (embodiment not shown).

According with yet another aspect of the invention, a monitoring system for an optical network is shown in fig 10. An optical network consists of a mesh-like structure
35 of network elements 30 being any transmission or signal manipulation component within the network, such as transmitters, receivers, transmission lines or fibers, disper-

sion compensating fibers, amplifiers, repeaters, regenerators, wavelength converters or optical cross-connects.

Since the transmission of the optical signals through a network depend on a lot of the status of different network elements, it is valuable to know when network elements fail, and how such failures affect the optical signal. Thereby, the inventive monitoring system comprises a plurality of monitoring stations 31, being placed in various positions in said network. The monitoring stations each comprises a monitoring unit as showed in fig 9, but may also be constituted by any other construction utilizing a monitor module 2 as described above. Each of said monitoring stations 31 is further connected to a central monitoring hub 32, receiving measured signal data from a plurality of monitoring stations 31, being deployed within said network. An example of such a system including monitor stations is shown in Fig 10. Here, the monitor stations 31, each comprising a monitoring module 2 are deployed between each network element 30. Each monitoring module 2 is able to measure basic parameters as function of wavelength as described above. For example, for a wavelength-division multiplexed optical network, it is possible to measure wavelength-division multiplexed data at the signal position, such as power, state of polarization and degree of polarization. The measured data from each monitoring module 2 is transmitted to a central monitoring hub 32 in which all monitored data of the transmission link is gathered. Said monitoring hub 32 further comprises a processing unit and an information display unit (not shown).

Given the input from the monitor modules 2 via the monitoring stations 32, the monitoring hub 32 will be able to

- Present the measured raw data, by means of said information display unit.
- Process the measured data by means of said processing unit, thus extracting information about:

- o signal power at each WDM (wave-length division multiplexed) channel.
 - o optical signal to noise ratio at each channel.
 - o degree of polarization of each channel.
 - 5 o the wavelength of each channel.
- Draw conclusions about network functionality, i.e.
 - o determine losses.
 - o determine noise figures and decay in OSNR (optical signal to noise ratio).
 - 10 o determine polarization mode dispersion (PMD)
 - o determine distortions from PMD
 - o determine mechanical motion of network elements
- Together with a priori knowledge of the network elements and input signal give information about
 - 15 nonlinearities, dispersive distortion and bit error rate probabilities.
- Do all the above as a function of time and thus be able to give information about trends and degradations that might cause outages of the network.

20 The monitoring system is above described with reference to a wavelength-division multiplexed optical communication network. However, the monitoring system may be used with any communication system in which the above-mentioned measured parameters are of interest.

25 Further it shall be noted that the spectrometer module as described above may be implemented in other ways than the ones described above, without departing from the scope and spirit of this invention, as described by the appended claims.

30 Moreover, it shall be explicitly noted that the spectrometer module are not only useful with the monitoring module, unit and system as described above, but may also be used for generating a stand-alone spectrometer device as is shown by way of example in fig 2, and as is described above.

35 As a summary, this document describes a signal monitoring system that uses a polarimeter in the spectrometry

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